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Visual perception of the arm manipulates the experienced pleasantness of touch

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ABSTRACT

Touch, such as a caress, can be interpreted as very pleasant. The emotional valence assigned to touch is likely related to certain bottom-up factors, such as optimal activation of C-tactile (CT) afferents. It is however unclear if besides somatosensory input, contextual factors related to the own body also play a role in the perceived pleasantness of touch. To test this, we manipulated visual appearance of the participant's arm (veridical vision, no vision, pixelated moving statistic projected onto the arm (i.e. crawling skin)). We used slow velocity stroking (CT optimal stroking) with a soft brush to induce pleasant touch, and fast velocity stroking as a control condition. After each visual condition we asked participants (N = 23) to rate the emotional valence of the stroking they felt. After slow velocity stroking ratings on perceived pleasantness (but not on perceived unpleasantness) were modulated by visual condition, with veridical vision of the arm resulting in higher pleasantness ratings than both no vision and pixelated vision. We conclude that contextual processes affect the perceived pleasantness of touch. These findings shed a new light on the underlying mechanisms of how humans experience pleasant touch and show that pleasant touch not solely dependents on bottom up information.

1. Introduction

Communication is crucial in daily life and human behavior is characterized by several means of interaction. An important and intuitive way to communicate our emotions during interpersonal interactions is through touch (Loken et al., 2009). Literature on touch does not only describe for example processes related to distinguishing between different touches and locating touch on the body surface, but it also addresses specific effects of *pleasant touch* (Loken et al., 2009). Previous studies described that touch from another person can be experienced as soothing (Feldman et al., 2010; Fairhurst et al., 2014) as well as pleasant (Loken et al., 2009). Furthermore, pleasant touch has been found to be very effective in providing social support (Loken et al., 2009), in influencing blood pressure and heart rate (Grewen et al., 2003), and in reducing stress and illness symptoms during an infection (Cohen et al., 2015).

Touch to the skin surface activates different myelinated as well as unmyelinated, mechanoreceptive afferents (e.g. McGlone et al., 2014). It is thought that C-tactile (CT) afferents, present in the hairy skin, play an important role in interpersonal touch. Activation of CT afferents depends on several factors: First, it has been shown that CT afferents are activated most strongly by gentle, caressing, stroking velocities of 1–10 cm/s (Loken et al., 2009; Ackerley et al., 2014). Second, CT afferents preferentially respond to tactile stimuli at human skin temperature (Ackerley et al., 2014). Indeed, previous studies reported that humans experience touch by another individual as more pleasant than self-touch (Ackerley et al., 2014), although, it appears that touch provided by a hand and a robot are perceived as equally pleasant (Triscoli et al., 2013).

Whereas we know that these factors are associated with the sensations characteristic of pleasant touch, these only shed light on the *somatosensory* properties of touch. It is unclear whether there are specific somatosensory properties of touch that by themselves can give rise to a pleasant interpretation of touch (Ellingsen et al., 2015). It is therefore crucial to include the contextual factors that may play a role in the subjective experience of pleasant touch (Ellingsen et al., 2015). Gazzola et al. (2012) for example showed that the interpretation of touch can switch from pleasant to unpleasant, if the preferences of the recipient are different from the intentions of the toucher. Ellingsen et al. (2014) found that the perceived pleasantness of touch could be manipulated by images of different emotional facial expressions. Furthermore, McCabe et al. (2008) showed that word labels presented while gently applying

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cream to the arm of a participant in a rubbing motion (i.e. "rich moisturizing cream" vs "basic cream") resulted in different subjective ratings of pleasantness of touch as well as different patterns of activation in the pregenual cingulate cortex and orbitofrontal cortex. Taken together these findings imply that contextual factors that evoke a certain expectation or preference appear to influence how touch is processed and interpreted/perceived subjectively (Ellingsen et al., 2015). At this point studies focusing on the modulation of perceived pleasantness of touch by contextual factors have mainly included external cues/information, such as the identity of the touchers or stimuli presented in conjunction with the touch. It is yet unknown whether contextual factors related to the *own body*, such as the visual appearance of the body part that is touched, also play a role in subjective evaluations of pleasant touch.

It has been reported that activity in primary somatosensory cortex can be modulated by visual information (Schaefer et al., 2006). Moreover, Rock and Victor (1964) found that the visual modality is *dominant*, for example in visuo-tactile conflicts that arise during multisensory bodily illusions (see e.g. de Vignemont, Ehrsson et al., 2005), such as the Rubber Hand Illusion (Botvinick and Cohen, 1998). Others found that tactile perception can be altered after manipulating visual information of the touched limb (i.e. enlarging it) (Taylor-Clarke et al., 2004; Longo et al., 2008). Visual dominance was also demonstrated by McKenzie and Newport (2015) using the so-called *crawling skin illusion* in which pixelated moving static was projected on real-time video images of the arms of participants. Although no actual bottom-up somatosensory input was provided, participant reported illusory sensations of touch (i.e. "crawling skin") on their skin (McKenzie and Newport, 2015).

Thus, several studies have shown that vision can modulate, and even interfere with, the perception of touch. It is however unknown whether vision of the own body also modulates perception of pleasant touch. To gain a deeper insight in the mechanisms underlying the subjective experience of pleasant touch, we will explore whether perceiving touch as pleasant mainly depends on activation of sensory afferents (e.g. CT afferents), or whether contextual information related to the own body, such as the visual appearance of the touched body part, can modulate the perceived pleasantness of touch. In order to optimally activate CT fibres and induce pleasant touch (Loken et al., 2009) we used slow-stroking velocities of 3 cm/s, following e.g. (van Stralen, van Zandvoort et al., 2014), as a control condition we used fast-stroking velocities of 30 cm/s, which have been reported to activate CT afferents less strongly compared to slower velocities (Loken et al., 2009). We compared subjective pleasantness ratings of touch during veridical vision of the touched arm, no vision, and during the crawling skin illusion previously used by McKenzie and Newport (2015). We expected that pleasantness ratings would be lower when participants were stroked during the crawling skin illusion compared to the veridical and no vision viewing condition. Previous work has shown that expectations about touch (induced with e.g. abstract cognitive labels) can influence the subsequent perception of pleasantness of touch (McCabe et al., 2008; Ellingsen et al., 2015). Since the crawling skin illusion generally gives participants (the expectation of) a tingly/tickly feeling (McKenzie and Newport, 2015), we expected this to modulate the pleasantness ratings in a negative way, as the expected sensations were incongruent with actual sensations (stroking with a soft brush). As the crawling skin illusion has not been reported to result in a threatening or highly undesirable context (McKenzie and Newport, 2015), we did not expect that ratings of *unpleasantness* of touch would be higher after the crawling skin illusion compared to after veridical or no vision (see also Ellingsen et al., 2015).

2. Methods

2.1. Participants

Twenty-three (22 females) healthy undergraduate students participated in this experiment. Mean age was 22.13 years (SD = 4.16). Twenty-two participants were right handed and one was left handed (self report). Before the start of the experiment participants provided written informed consent. The study was conducted in accordance with the Declaration of Helsinki.

2.2. Materials and procedure

At the start of the experiment participants were instructed to place their hands in a MIRAGE system with their palms down (Newport et al., 2010). In the MIRAGE the arms of participants were placed underneath a mirror. This mirror was horizontally suspended and filmed by a camera which was connected to a laptop. The laptop was connected to a 28 inch screen. This screen was positioned on top of the MIRAGE box and projected the real-time video of the arms to another mirror. Participants were able to see this mirror, which allowed them to watch their arms and hands in real time and in the same spatial location as their actual arms and hands were positioned.

Using MIRAGE software three different viewing conditions were constructed; veridical vision (see Fig. 1A), no vision (i.e. blue screen, see Fig. 1B), and pixelated vision (i.e. crawling skin illusion, following McKenzie and Newport (2015), see Fig. 1C). In each trial participants were made accustomed with viewing their arms in the MIRAGE by touching each finger with their thumb for 20 s. Afterwards participants were instructed to keep their arms and hands still, and the experimenter started stroking the hairy skin of the left arm (dorsal side) with a soft foundation brush for 30 s. Stroking was either of slow velocity or fast velocity, resulting in a total of 6 different conditions (i.e. 2 (touch: slow vs. fast velocity) × 3 (vision: veridical vision vs no vision vs pixelated vision) design), which were all repeated twice within subjects in a randomized order.

Following previous work in our group (van Stralen et al., 2014) the experimenter was trained in stroking participants in a standardized manner at the right velocities in each condition. Slow stroking corresponded to a velocity of 3 cm/s over a length of 10 cm, resulting in approximately 10 stroking movements in each 30-s trial. Fast stroking corresponded to a velocity of 30 cm/s over a length of 10 cm, resulting in approximately 90 stroking movements in each 30-s trial.

At the end of each trial participants removed their arms from the MIRAGE and were asked to rate the pleasantness of stroking using the Touch Perception Task (TPT) questionnaire (Guest et al., 2011). The

Fig. 1. Manipulations induced with the MIRAGE system.
Note. Panel A depicts veridical vision; Panel B depicts no vision (i.e. blue screen); Panel C depicts pixelated vision (i.e. crawling skin illusion).

TPT consists of 14 items, which assesses the emotional evaluation of touch. Ackerley et al. (2014) divided these 14 items into three subscales: Positive; negative; and arousal. Here we used the TPT positive (7 items) and TPT negative subscale (3 items). Participants rated on the TPT positive subscale how comfortable, enjoying, soothing, relaxing, calming, pleasurable, and desirable they perceived the stroking on their skin to be using a VAS scale for each item ranging from “not descriptive at all” to “very highly descriptive”. For the TPT negative subscale participants rated how thrilling, irritating, and discomfortable the stroking on their skin was. Higher scores reflected a more positive evaluation of touch (TPT positive) or more negative evaluation of touch (TPT negative). As each condition was repeated twice, we calculated the mean score over these two repetitions for both the TPT positive items and for the TPT negative items. We have only included the positive and negative subscale of the TPT as the main focus of the experiment was on how *pleasant* participants would rate touch. The negative subscale was included as the slow stroking condition intended to induce pleasant touch, while the fast stroking condition served as a control condition in which we wanted touch to be not pleasant, but also not *unpleasant*. The experiment ended with obtaining demographic information from participants (gender, age, handedness).

3. Results

3.1. Touch perception task (TPT) positive subscale

To test whether visual appearance of the arm could affect the perceived *pleasantness* of positive affective touch, a 2 (touch: slow vs. fast velocity) × 3 (vision: veridical vs. no vision vs. pixelated) repeated measures ANOVA was performed on ratings of TPT positive items.

A main effect for type of touch was found ($F(1,22) = 14.68$; $p = 0.001$). Slow velocity stroking was rated as significantly more pleasant on TPT positive ($M = 6.23$, $SD = 1.67$) than fast velocity stroking ($M = 5.00$, $SD = 1.85$). No main effect for vision was found ($F(2,44) = 0.47$, $p = 0.628$). However, a significant interaction effect was identified between touch and vision ($F(1.20,26.29) = 5.11$, $p = 0.027$, assumption of sphericity was violated, results are reported following the Greenhouse-Geisser correction), see Fig. 2.

Post hoc Bonferroni corrected paired samples *t*-tests showed that TPT positive ratings after veridical and no vision differed significantly in the slow velocity stroking condition ($t(22) = 2.84$, $p = 0.009$) with higher TPT positive scores for veridical vision than for no vision. No differences in TPT positive ratings after veridical and no vision were found in the fast velocity stroking touch condition ($t(22) = 1.93$, $p = 0.066$). A difference between TPT ratings after veridical and pixelated vision was found in the slow velocity stroking condition ($t(22) = 3.67$, $p = 0.001$), with higher TPT positive scores for veridical vision than for pixelated vision. This effect was absent in the fast velocity stroking condition ($t(22) = 0.29$, $p = 0.773$). No significant difference in TPT positive ratings after no vision and pixelated vision was found in both the slow ($t(22) = 1.37$, $p = 0.184$) and fast velocity stroking condition ($t(22) = -1.62$, $p = 0.120$). Note that p-values were Bonferroni corrected to $\alpha = 0.017$. See Table 1 for an overview of means and SD’s.

Taken together, the results showed that perceived the perceived pleasantness of touch was modulated by visual appearance of the arm. Participants rated slow velocity stroking as most pleasant under veridical vision conditions compared to both pixelated (i.e. crawling skin) vision and no vision of their arm.

3.2. Touch perception test (TPT) negative subscale

To test whether visual appearance of the arm could affect perception of negative aspects of pleasant touch, a 2 (touch: slow vs. fast velocity) × 3 (vision: normal vs. no vision vs. pixelated) repeated measures ANOVA was performed on ratings of TPT negative items. We mainly included the TPT negative subscale as a manipulation check, to ensure that stroking did not evoke negative emotions, as we aimed to induce a pleasant stroking experience with slow velocity stroking, and a “neutral” (neither pleasant, nor unpleasant) with the fast-velocity control condition. Neither a main effect for type of touch ($F(1,22) = 0.67$, $p = 0.421$) nor type of vision ($F(2,44) = 0.60$, $p = 0.554$) was found. There was no significant interaction between touch and vision ($F(2,44) = 2.15$, $p = 0.129$). See Table 1 for an overview of means and SD’s. Taken together the results show that the negative evaluation of touch did not differ between slow and fast velocity stroking conditions, nor between different vision conditions.

4. Discussion

The aim of the current study was to get a better understanding of mechanisms underlying the subjective experience of pleasant touch. It is generally accepted that only under certain circumstances CT fibres show an optimal firing rate (e.g. McGlone et al., 2014). In order for touch to optimally activate CT fibres, the hairy skin should be touched (e.g. Olausson et al., 2002; Ackerley et al., 2014a) in a slow, gentle (e.g. Loken et al., 2009) velocity using soft material (e.g. van Stralen et al., 2014) at human skin temperature (e.g. Ackerley et al., 2014b). Once CT

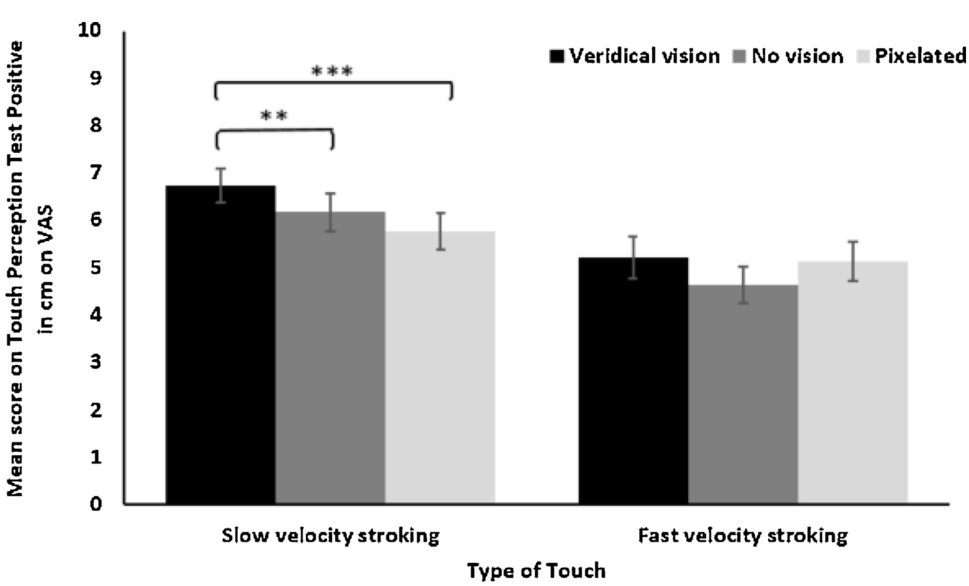

Fig. 2. Mean scores on the positive items of the Touch Perception Task by type of touch (slow velocity stroking vs high velocity stroking) and vision (veridical vision vs. no vision vs. pixelated vision (i.e. crawling skin)).
Note. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; error bars depict SEM.

Table 1
Mean ratings and SD's on the positive and negative items of the Touch Perception Task (TPT) by type of touch (slow velocity stroking vs. fast velocity stroking) and vision (veridical vision vs. no vision vs. pixelated vision (i.e. crawling skin)).

	Positive items Touch Perception Task				Negative items Touch Perception Task			
	Slow stroking		Fast stroking		Slow stroking		Fast stroking	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Veridical vision	6.73	1.74	5.22	2.18	2.03	1.36	2.70	1.94
No vision	6.17	1.86	4.64	1.88	2.61	1.97	2.89	2.08
Pixelated	5.77	1.82	5.13	2.02	2.32	1.51	2.70	1.87

afferents are activated optimally by touch, this touch can be interpreted as very pleasant by the receiver. However, there are several studies that have shown that the emotional valence (i.e. pleasant or unpleasant) attributed to CT optimal touch not only depends upon bottom-up sensory signals, but also on contextual factors (e.g. Gazzola et al., 2012; Ellingsen et al., 2014). We were interested in whether the visual context in which touch is provided, specifically the visual appearance of the own arm, modulates the perceived pleasantness of touch.

Previously the modulating role of vision in touch perception has been investigated with respect to discriminative touch. Several authors showed that vision of the touched body part altered perception of touch (e.g. Longo et al., 2008). For example, perception of the distance between two tactile stimuli was altered after manipulating visual input of the touched body part (Taylor-Clarke et al., 2004). Furthermore, visual input is found to be dominant during visuo-tactile conflicts when inducing multisensory illusions (de Vignemont et al., 2005), such as the Rubber Hand Illusion (Botvinick and Cohen, 1998).

Here we specifically investigated whether the interpretation of pleasant touch was regulated mainly by bottom-up activation of sensory fibres, such as CT fibres, or whether visual input of the stimulated body part could influence how participants subjectively perceived and evaluated pleasant touch. We did so by asking participants to rate the emotional valence of touch after manipulating vision of the arm (veridical vision vs no vision vs "crawling skin" (McKenzie and Newport, 2015)) while stroking the arm (slow velocity vs fast velocity).

The results showed that participants rated slow velocity stroking as more pleasant than fast velocity stroking after all three vision conditions. This suggests that our slow-velocity stroking condition indeed was interpreted as "pleasant touch" and has likely activated CT afferents that play an important role in the emotional valence of touch, and as such replicating previous findings (Loken et al., 2009; van Stralen et al., 2014). More importantly, we found that after slow-velocity stroking, participants' pleasantness ratings of touch were dependent upon the visual condition. Specifically, slow velocity stroking was rated as most pleasant when participants had veridical vision of their arm, and as less pleasant after their arm was occluded from view (no vision) or when moving white noise was projected onto their arm (i.e. pixelated vision, crawling skin). We did not identify any differences between different visual conditions in evaluations of negative, unpleasant, aspects of touch. We did not expect to find any effects on unpleasantness of touch, as the experimental setting and the provided touch evoked in no way a negative vibe (e.g. touch was conveyed with a soft brush). We mainly included the negative subscale of the TPT as a manipulation check, to ensure that our touch indeed did not evoke negative emotions.

Taken together, our findings indicate that the experienced pleasantness of touch can be influenced by manipulating the visual appearance of the touched body part, but only at the level of positive emotions associated with the felt touch. In line with findings from previous work on discriminative touch (e.g. Taylor-Clarke et al., 2004; de Vignemont et al., 2005; McKenzie and Newport, 2015), it appears that the modulating effect of vision on touch perception extends to pleasant touch as well. Therefore, the subjective perceptual experience of pleasant touch seems to not only rely on the bottom-up somatosensory input, in particular optimal activation of CT afferents, but can be influenced by contextual visual information concerning the own body.

Contextual modulation of touch perception has also been reported by McCabe and colleagues with respect to cognitive input (McCabe et al., 2008). They reported changes in experienced pleasantness of touch on the hairy skin by manipulating word labels that were shown during CT optimal stroking (i.e. *basic* cream vs *rich enhancing* cream is being rubbed on the skin). Differences in activity in the orbitofrontal cortex were reported as well (McCabe et al., 2008). The authors conclude that processing and subjective perception of CT optimal touch is thus susceptible to cognitive biases, such as the language-induced expectation of how touch might feel. Other researchers have also shown and stressed the importance of the context in which touch takes place (see e.g. Gazzola et al., 2012; Ellingsen et al., 2014; Ellingsen et al., 2015). Gazzola et al. (2012) for example identified a modulating role of the expected sex of the toucher on processing of a sensual caress. Similarly, the pixelated moving static we projected onto participants' arms (i.e. crawling skin) might have evoked certain expectations about the emotional valence of touch. Especially since this visual manipulation has been found to induce a tingly sensation in participants (McKenzie and Newport, 2015), which was also reported spontaneously by participants in our sample. It could be that during the crawling skin illusion participants expected the slow velocity stroking to be less pleasant, as it would be incongruent with their illusionary tingly sensations. Perhaps our findings show that just as CT afferents have an optimal firing rate that is achieved under certain circumstances, there are also certain circumstances that promote optimal pleasantness experiences. It is possible that when the expectations about touch are incongruent with the provided touch, this might result in sub-optimal ratings of pleasantness, but not necessarily in interpretation of the touch as *unpleasant*. Contrary to our expectations we did not find that the crawling skin condition resulted in the lowest pleasantness ratings, but rather that veridical viewing conditions resulted in the highest pleasantness ratings. This may indicate that the condition in which signals were most congruent is optimal for high pleasantness, compared to no signal at all (no vision) or an incongruent signal (crawling skin). Taking previous findings (e.g. McCabe et al., 2008; Gazzola et al., 2012) and our current findings into account, it seems that the perceived pleasantness of touch relies on a complex combination of peripheral, e.g. CT afferent, input as well as on cognitive and visual contextual information that is provided in conjunction with slow-velocity stroking of the hairy skin.

What is remarkable is that we found the modulating effect of visual information of the own body on pleasantness ratings only for the slow velocity stroking condition, not for the fast velocity stroking condition. This could indicate that the effect is somehow dependent upon CT optimal stroking speeds. To gain more insight in the interplay between incoming peripheral information and contextual top-down influences on the perceived pleasantness of touch, it would useful to include stroking of the glabrous skin, where CT afferents are thought not to be present (see e.g. Ackerley et al., 2014a).

Future replication of our results are required to further identify the modulating role of visual information on the own body in the evaluation of pleasant touch. It would also be interesting to investigate whether an increase in sample size would result in findings significant differences in how no vision vs crawling skin is rated in terms of pleasantness and unpleasantness. Such an experiment would provide an interesting stepping stone for clinical research focusing on e.g. realistic prostheses or on individuals suffering from skin conditions such as eczema or severe burns. As interpersonal touch can have soothing (e.g. Feldman et al., 2010; Fairhurst et al., 2014) and beneficial (health) effects (Cohen et al., 2015), using touch in treatment of for example (chronic) itch or pain may be worthwhile. It could be that patients suffering from eczema experience less itch after slow velocity stroking while viewing a version of their arm that is not affected by the eczema compared to a veridical view of their arm (including eczema), or perhaps this patient group would benefit more from slow velocity stroking without any visual input of their arm.

A limitation of the current experiment that should be addressed in future studies is that we adopted a temporal paradigm. In other words, in each condition participants were stroked for 30 s (following van Stralen et al., 2014). Although there was a temporal match between all conditions, the relative amount of tactile input differed, as in the slow velocity condition participants were stroked 10 times, while in the fast velocity condition participants were stroked 90 times, which resulted in more skin contact in the latter condition.

Nevertheless, our results provide an interesting first basis from which modulating effects of vision of the own body on the perceived pleasantness of touch can be further explored. It appears that, in order to create a pleasant touch experience, it is not only crucial to ensure optimal bottom-up activation of sensory fibres, such as CT-afferents, but the visual context in which touch is provided should be taken into account as well, specifically the visual appearance of the touched body part.

Conflict of Interest

None.

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